DATA 420 — Modeling and Simulation

Professor: Stephen Davies
Spring 2026

Lecture:
TR 3:30–4:45pm, Farmer 026

Office Hours (James Farmer Hall 044):
Mon	12–2pm
Tue	10–11am
Thu	12–2pm

Final exam: Tuesday, April 28, 3:30-6pm

`http://stephendavies.org/data420`

Computers are tools that can help us understand our world.

It's true, of course, that computers do many other things as well: they store and retrieve information, carry out financial transactions, and display 3-D graphics of spaceships. For this reason, we're sometimes likely to see computer programs principally in terms of what we can build with them, rather than what we can learn from them.

This class, by contrast, is about seeking *understanding*, not about building applications or devices.

For a long time, there have essentially been two ways to gain knowledge. The first one — *theory* — goes back to before Aristotle. We analyze our world, using our reason, and come up with simplifications, abstractions, and categorizations that help us make sense of it. Around the 17$^{\text{th}}$ century, a second method came on the scene: *experimentation.* Instead of just speculating about how things behave, we subjected Nature (and People) to principled testing, seeing if we could reliably and repeatably predict how they will respond.

The 20$^{\text{th}}$-21$^{\text{st}}$ centuries introduced a third way: *modeling and simulation.* This new paradigm, made possible by the digital computer, helps us answer some questions

that were unanswerable previously. Estimating the energy in a nuclear chain reaction? Plotting the trajectory of a hurricane? Predicting the outcome of a political revolution? Anticipating how large a city can get before its crime rate increases? None of these problems or thousands of others are solvable without adding this powerful third weapon to our arsenal.

At the center of this new approach are abstract computational models that extrapolate outcomes from innumerable tiny elements and rules. And the complexity that we see arising from lots of simple things interacting in seemingly simple ways is breathtaking.

We technologists have a powerful skill set which can further our knowledge of society and of the universe. The amazing thing is that without even getting our hands dirty in a petri dish, the programs we write shed real light on real problems. Our models and their simulations *become* the science in a very real way, as we leverage the computer to attack the grand challenges of our age.

Course Objectives

- To give you a high-level overview of the techniques, promises, and limits of computational modeling as a way to understand complex phenomena.

- To tie together the two halves of Data Science. Whereas a course like 419 (Data Mining) is about analyzing data to infer properties about the process that generated it, 420 is about creating models of the process itself and seeing whether the data it generates matches up. It's kind of like 419 in reverse.

- To introduce you to some of the important modeling and simulation paradigms, with a special focus on two: System Dynamics, and Agent-Based Modeling. Also, to give you plenty of practice implementing and analyzing such models!

- To explore the emerging field of LLM-enhanced ABMs: agent-based models whose agents, rather than being composed of fixed rules in (say) Python code, are instead implemented by Large Language Models who make more sophisticated decisions.

- Finally (and seriously) to improve your understanding of life in general and make you a better thinker.

Student Learning Outcomes

After completing this course, students will be able to...

- ...identify the different subfields within the modeling and simulation field, and to explain their techniques, promises, and limits as a way to understand complex phenomena.
- ...explain how modeling and simulation (DATA 420) – producing and analyzing the data from a simulated model – is the inverse of data mining (DATA 419) – reasoning from observed data backwards to a plausible model.
- ...design and implement programmatic models in both the Systems Dynamics and Agent-Based Modeling paradigms, including Large-Language-Model-based Agent-Based Models, and accurately interpret their results.
- ...wield a new set of quantitative tools to assess uncertainty, think more critically, and form conclusions more reliably.

Rules of the game

1. There are absolutely, positively, NO stupid questions!! Your job is not to already know everything before you start the course. Your job is to try hard to learn, and part of that involves asking questions. I'm a nice guy, and I will not ever belittle you, snub you, or make fun of you; and if anyone else does so I will personally break both of their arms.
2. This class will be interactive. When I point at you in class, say your first name, and be prepared to try and answer questions. (Don't worry if you don't know all the answers.)
3. This class involves a good bit of reading. This is because the class involves a good bit of learning, and with apologies to this video-centric generation, most deep learning still comes through reading. Part of what you should get out of this class is an improvement in your reading habits. I'll work hard on my end to try and make that happen, since I think becoming a more efficient and effective reader is actually **the** most important thing you can get out of college, period. What *you* need to do is have a good attitude about it and dedicate yourself to rolling up your sleeves and digging in.
4. Don't skip class. Just don't. It's bad form. I work hard to prepare for class, to make it compelling and relevant. It hurts my feelings when you don't come. Plus you miss out on important stuff, and you'll end up falling behind if you

skip lecture. So come every time. Come happy, fresh, excited, ready to think and to participate.

5. **Absolutely no laptops, cell phones, or other devices during class.**[*] I've had students claim that they take notes on their laptop during lecture, but even if it's true, those things are way too big a distraction to you and your fellow students to make it worth it. Just stay tuned in, because I move fast.

6. For any Zoom class that may take place this semester, **you must have your webcam on during the entirety of the lecture.** If you don't have a working Webcam, buy one immediately.

The Honor Code and this course

For this course, **all the work that you turn in for a grade must be solely your own work, period.** Specifically, this means:

- The reading checks must be taken without looking at the book and without help from anyone.
- The Canvas quizzes must be taken alone, in a quiet place, without any form of contact with anyone.
- **You must not use any part of any other student's Python code.** You may not directly copy any part of anyone else's program. That being said, it is okay to work alongside classmates in a study group, and you are allowed to talk through homework assignments, ask others how they solved a particular problem, and so forth. **If you do this, you must name all the people you worked with on your homework submission.** If you fail to give this information clearly on your homework submission, it is an Honor Code violation.
- You *are* permitted to use AI (such as ChatGPT) while working on the homeworks, but **in your submission you *must* include link(s) to all the chat(s) you created while working on it.** If you fail to give this information clearly in your homework submission, it is an Honor Code violation.

---

[*]Obviously "no laptops" doesn't apply to any Zoom sessions we might have. The "no cell phones or other devices" rule does, however.

Books

- Silver, N. (2015). *The Signal and the Noise: Why So Many Predictions Fail – But Some Don't*, New York, NY: Penguin Books, 2015.

The hugely influential Nate Silver (previously of `fivethirtyeight.com` fame) got his start forecasting statistical outcomes for major league baseball players, of all things. But has since done incredibly broad and ground-breaking work analyzing statistical models of all kinds. His book *The Signal and the Noise* is hands-down one of the best books I have ever read, and has literally changed the way I look at life. It is particularly relevant to this class, as Silver has years of sober-minded expertise to share about simulations and their predictions.

Silver has also been parodied on Saturday Night Live, so there's that.

Late policy

No late work will be accepted this semester. Get your stuff in on time!

Grading

Grading this semester will be based on "experience points" (XP). As you complete activities, you will earn XP towards your final total. XP can never be lost, only gained, but you have to earn what you get (*i.e.*, you don't "start off with a 100%" and lose points based on mistakes you make).

There will be opportunities to earn XP throughout the course. Some of these will be spontaneous as the mood strikes me. Some you can earn by completing in-class activities. Some may be in response to impressive things I see you do as the semester progresses. The following opportunities, however, are *guaranteed* to be available to you:

Guaranteed XP opportunities:

Activity	Possible XP
One-minute reading checks	4 each
Six open-book, open-note, timed Canvas quizzes	30 each
Seven programming assignments	40 each
Final exam (comprehensive)	100
Various and sundry others	varies

The one-minute "reading checks," by the way, are **closed**-book, **open**-note, and will take place at exactly 3:30pm at the start of most class periods. These are intended just to hold you accountable to the reading for the day, and should be easy as long as you have.

Grading levels

Here are the levels you may achieve:

Level	Total XP	Semester grade
The Doctor	**700**	A+
Spock	**660**	A
Dr. Hari Seldon	**600**	A–
Dr. Susan Calvin	**560**	B+
Shuri	**520**	B
Dr. Liet-Kynes	**480**	B–
Dr. Bruce Banner	**440**	C+
Dr. Ellie Satler	**400**	C
Dr. Jane Foster	**360**	C–
Dr. Miles Bennett Dyson	**330**	D+
Dr. Eleanor Arroway	**300**	D
Dr. Mark Watney	**265**	
Dr. Stephen Falken	**230**	
Felonius Gru	**200**	
Dr. Emmitt "Doc" Brown	**175**	
Buddy Pine	**150**	
Dr. Joseph Albert Nefario	**125**	
Dr. Sheldon Lee Cooper	**100**	
Dr. Leonard Leakey Hofstadter	**80**	
Dr. Peter Venkman	**50**	
Dr. Bunsen Honeydew	**20**	
Jimmy Neutron, Boy Genius	**5**	
Beaker	**0**	

Submitting programs

Rules for submitting programs will be given when the program is assigned. Most of the time, you'll be emailing me your program code as an attachment, and using a specific subject line to distinguish it from my hordes of other email. Meeting the deadline is a matter of sending your email before time expires.

Also, most of my homeworks are due at "midnight." Here's what "midnight" means: if a homework is due "at midnight on Thursday," then it is due after all of Thursday has elapsed, and the clock strikes twelve. (In other words, this is good news: you have all Thursday to work on it.)

Basis for determining mid-semester reports

For midterm progress reports, I look mostly at (1) whether you've been turning assignments in (and preferably on time), and (2) your reading checks and quiz scores. If either or both of these categories are lacking, it's a sign of danger, and I will give you a "U" for your mid-semester grade. Please don't hesitate at all to come talk to me about this so we can figure out how you can do better in the course.

Guidelines for class participation

I believe that students learn best when they participate wholeheartedly in all aspects of the learning process. Hence while your grade will not be partially determined by any "class participation score" *per se*, it is very much to your advantage, and very much recommended, that you join in during class discussions, ask questions, and make comments.

Disabilities

If you have a documented disability, please present me your letter from the Office of Disability Resources and I'll be happy to accommodate you.

Guidelines for class participation

I believe that students learn best when they participate wholeheartedly in all aspects of the learning process. Hence while your grade will not be partially determined by any "class participation score" *per se*, it is very much to your advantage, and very much recommended, that you come to lecture every single class period, and participate fully in it.

Title IX Statement

UMW faculty are committed to supporting students and upholding the University's *Policy on Sexual and Gender Based Harassment and Other Forms of Interpersonal Violence.* Under Title IX and this Policy, discrimination based upon sex or gender is prohibited. If you experience an incident of sex or gender based discrimination, we encourage you to report it. **While you may talk to me, understand that as a "Responsible Employee" of the University, I** must **report to UMW's Title IX Coordinator what you share.** If you wish to speak to someone confidentially, please contact the confidential resources below. They can connect you with support services and help you explore your options. You may also seek assistance from UMW's Title IX Coordinator; their contact information can be found below. Please visit `http://diversity.umw.edu/title-ix/` to view *UMW's Policy on Sexual and Gender Based Harassment and Other Forms of Interpersonal Violence* and to find further information on support and resources.

Resources
Ruth Davison, Ph.D.
Title IX Coordinator
Lee Hall, Room 401
540-654-5656
`rdavison@umw.edu`

Confidential Resources
On-Campus
  Talley Center for Counseling Services
  Lee Hall 106, 540-654-1053

  Student Health Center
  Lee Hall 112, 540-654-1040

Off-Campus
  Empowerhouse (24-hr hotline)
  540-373-9373

  RCASA (24-hr hotline)
  540-371-1666

Recording Policy

Classroom activities in this course may be recorded by students enrolled in the course for the personal, educational use of that student or for all students presently enrolled in the class only, and may not be further copied, distributed, published or otherwise used for any other purpose without the express written consent of the course instructor. All students are advised that classroom activities may be taped by students for this purpose. Distribution or sale of class recordings is prohibited without the written permission of the instructor and other students who are recorded. Distribution without permission is a violation of copyright law. This policy is consistent with UMW's *Policy on Recording Class and Distribution of Course Materials.*

Accessibility statement

The Office of Disability Resources has been designated by the university as the primary office to guide, counsel, and assist students with disabilities. If you receive services through the Office of Disability Resources and require accommodations for this class, please provide me a copy of your accommodation letter via email or during a meeting. I encourage you to follow-up with me about your accommodations and needs within this class. I will hold any information you share with me in the strictest confidence unless you give me permission to do otherwise.

If you have not made contact with the Office of Disability Resources and have reasonable accommodation needs, their office is located in Seacobeck 005, phone number is (540) 654-1266 and email is `odr@umw.edu`. The office will require appropriate documentation of disability.

Basic needs security

Learning effectively and engaging wholly in class is dependent upon our basic security and having our fundamental needs met: having a safe place to sleep at night, regular access to nutritious food, and some assurance of safety. If you have difficulty affording groceries or accessing sufficient food to eat every day, or if you lack a safe and stable place to live, please contact Chris Porter, Assistant Dean of Students, at `cjporter@umw.edu`. Additionally, the Gwen Hale Resource Center is a free resource on campus, providing food, toiletries and clothing to any member of our community.

It is open Monday, Tuesday and Friday from 1pm-6pm, on the 5th floor (floor A for Attic) of Lee Hall, or `resource@umw.edu`. Finally, you are always welcome to talk with me about needs, if you are comfortable doing so. This will enable me to provide any resources I may possess.

How to reach me

Come to office hours, see me after class, or e-mail me (`stephen@umw.edu`).

Calendar

(Note: the **official** calendar for the course, complete with assignment due dates, tests, etc., will be maintained on the course website at `http://stephendavies.org/data420`.)

Week	Topics	Readings	Due
1	Modeling and Simulation overview	Asimov: "Foundation"	
2	Modeling and Simulation principles System Dynamics modeling: • Stock & flow diagrams • Numerical calculus	Silver: Preface & Intro Numerical calc. tutorial	(HW #0)
3	Exponential and logistic growth patterns	Silver: ch. 1	HW #1
4	SD system patterns and analysis	Silver: ch. 2	
5	SD models: • Lotka–Volterra • Competitive exclusion • SEIR	Silver: ch. 3	HW #2
6	Stochastic models Probability in Python Random walks Pólya vs. Markov processes	Silver: ch. 4 Prob/stat tutorial	
7	Agent-Based Modeling concepts	Silver: ch. 5	HW #3
8	*Spring break*		
9	ABM models: • Boltzmann • Granovetter • El Farol • Prisoner's Dilemma	Silver: ch. 7	HW #4
10	Grid-based and graph-based ABMs	Silver: ch. 8	
11	ABM models: • Schelling • Grid-based SEIR • Binary Voter Model	Silver: ch. 10	HW #5
12	Parameter sweeps and parallelism	Silver: ch. 11	
13	ABM models: • Degroot • Hegselmann-Krause • Axelrod cultural diffusion	Silver: ch. 12	HW #6
14	LLM concepts and implementation	`llamacpp` tutorial	
15	LLM-enhanced Prisoner's Dilemma	Silver: ch. 13	HW #7